XIV. "On the early Development of Cirripedia." By THEO. T. GROOM, B.A., B.Sc., F.G.S., Demonstrator in Zoology at the Yorkshire College, Leeds, late Scholar of St. John's College, Cambridge. Communicated by ADAM SEDGWICK, F.R.S. Received May 11, 1892.

(Abstract.)

During a month's occupation of a table at the Marine Biological Laboratory of Plymouth, in the summer of 1889, and a nine months' occupation of the Cambridge University Table at the Zoological Station of Naples, commencing in the October of the same year, I had the opportunity of studying the development of a number of Cirripedes. Since that time, investigations on the same group have been carried on chiefly in the Morphological Laboratory at Cambridge.

I have been wishful to take up this subject, because the embryology of Cirripedia had been considerably neglected since the introduction of the more modern methods of investigation, and because the development might reasonably be expected to throw light on the adult structure of this interesting group. I wished, moreover, to compare the development in several species, with the object of throwing some light on larval evolution in general.

The species studied were *Lepas anatifera*, Linnæus; *Lepas pectinata*, Spengler; *Conchoderma virgata*, Spengler; *Dichelaspis Darwinii*, Filippi; *Chthamalus stellatus*, Poli, and *Balanus perforatus*, Bruguière.

Of *Dichelaspis*, only mounted specimens of the nauplii were examined, but in the other forms the development from the freshly-laid ovum to the second nauplius stage was investigated.

I had expected to find notable differences in the development of the different forms, but, although most of the genera could be distinguished at an early age, by some feature or other, the general course of development was very uniform, and the following summary is applicable to all the members of the group:—

The freshly-laid ovum consists of granular protoplasm, hollow yolk granules, and oil globules. Its size has much more relation to that of the nauplius than to that of the adult.

First polar body is given off, not in the ovary, but in the mantle cavity, though the first directive spindle is evidently formed in the ovary. The polar body is formed independently of, and probably before, or simultaneously with, fertilisation.

Fertilisation takes place in the mantle cavity before the peri-vitelline membrane is formed.

The emission of the first polar body is immediately followed by the formation of the vitelline (or peri-vitelline) membrane, which arises

while the egg is in the mantle cavity, whether the egg has been fertilised or not.

If fertilisation has not taken place, no further change ensues, and the egg does not contract; a second polar body is probably formed, but owing to the resistance of the peri-vitelline membrane cannot emerge, and is not seen.

If fertilisation has taken place, the egg diminishes in size, and commences to undergo rhythmical contractions, which cease only when the protoplasmic and yolk portions are completely separated.

The diminution in size is soon followed by the protrusion of clear amœboid processes at the anterior end of the egg, which are as often withdrawn: from this amœboid arises the second polar body, like the first, by the division of the nucleus in the ordinary karyokinetic manner.

The protoplasm generally collects at the anterior (larger) pole, and the yolk at the posterior (pointed) pole, in the well-known way. The process does not represent a total division, as has been supposed, into ectoderm and endoderm, but the formation of a teleolecithal egg, the protoplasmic part of which will form the first blastomere, and now rests upon a yolk portion, at first devoid of a special nucleus, but still in communication with the protoplasmic half.

The nucleus, at first small and peripherally situated at the anterior pole (invisible without special preparation), becomes visible as a clear spot or vesicle—the segmentation nucleus—occupying the centre of the protoplasmic half of the egg.

The nucleus divides, one daughter-nucleus remaining in the protoplasm, and the other passing into the yolk, the elements of which it has the power of transforming into protoplasm; this, together with the bulk of any protoplasm left in the yolk, now emerges as a second blastomere at the side of the first, which has in the meantime become cut off from the yolk.

The yolk becomes gradually covered by the successive emergence of fresh cells, which process is accompanied by the division of the cells cut off from it. The nucleus of these emerging protoplasmic bodies or *merocytes* is given off either from a peripheral blastomere, which has not yet been cut off from the yolk, or from a merocyte which divides before emerging as a blastomere. The yolk may be regarded as having the value of a single cell (macromere), which gives off a succession of blastomeres (micromeres) much in the same way as in the case of the epibolic eggs of *Bonellia*, where, however, there are four macromeres, each of which behaves in the same way.

The point where the blastoderm last covers the yolk represents (except possibly in rare cases) the blastopore, the nucleus which gives rise to both endoderm and mesoderm arising at or close to the same spot.

After separation of the epiblast the yolk cell or macromere remains still as a cell with a single nucleus, derived from that of the merocyte which formed the last or one of the last blastomeres. This yolk cell represents both mesoblast and hypoblast.

The meso-hypoblast cell immediately divides into two cells, one situated more dorsally, the other more ventrally. Each of these contains mesoblastic and hypoblastic elements. The mesoblast is formed by the cutting off in succession of segments from each of the two meso-hypoblast cells; these form a plug of rapidly dividing cells just in front of the closed blastopore. When all the mesoblastic cells are cut off the two yolk cells left remain as the first two hypoblast cells.

The two cells thus formed become divided into smaller yolk endoderm cells equivalent to the secondary yolk pyramids of Decapods (Reichenbach's *Secundäre Dotterpyramiden*).

Each yolk pyramid becomes later converted into an endoderm cell by radial contraction in a centrifugal direction, accompanied by gradual retreat of the nucleus to the periphery; the archenteric cavity arises by the separation thus caused of the central portions of the pyramids from one another.

The alimentary canal arises in three divisions, as in the Arthropoda generally, the stomach being formed mainly from the yolk endoderm, and the lining of the œsophagus and intestine probably wholly as long epiblastic ingrowths (stomodæum and proctodæum).

The mesoblastic cells of the nauplius, arising in the way described, divide up rapidly and extend forward between the ectoderm and endoderm as a dorsal plate; this soon grows down at the sides, but does not at first extend to the ventral surface.

This plate is chiefly concerned in the formation of the muscles of the nauplius appendages, which arise, as is probably the case in all nauplius forms, with the free ends directed dorsally.

The appendages are marked out first by two transverse furrows dividing the embryo into three segments; these occur only across the dorsal surface and up the sides, not extending into the ventral surface. Very soon the dorsal surface becomes traversed by a median longitudinal furrow, which does not extend to the ends of the body, but is bounded by two new transverse furrows; these furrows mark out an anterior and posterior (caudal) unpaired lobe with the free ends of the appendages between them on the dorsal, and not, as has always been stated for Cirripedes, on the ventral surface.

The antennules, antennæ, and mandibles are probably serially homologous, as indicated by their similarity in the free nauplius, and by their remarkable and similar origin; all may represent primitively post-oral appendages.

There are no mesoblastic somites at any period of embryonic

development; but the mesoblastic layer becomes thickened locally to form the muscles of the appendages in each of the three segments.

The body cavity* of the nauplius arises later as a mixed blastocœle and schizocœle, due in part to the separation of ectoderm and endoderm, and in part to an excavation of mesoblastic tissue. It soon forms a cavity continuous from end to end of the body.

The nervous system of the nauplius (arising as usual as an epiblastic thickening) shows from the beginning a complex structure, especially in the Balanids, and among these it is most specialised in the Balaninæ. It is probably from the first a syn-cerebrum, since it includes, in addition to the representative of the archi-cerebrum, the ganglia supplying the antennules. The antennæ and mandibles are in close relation with the circum-œsophageal connectives and sub-œsophageal ganglion respectively.

A comparatively sudden change is experienced by the nauplius in passing from stage I to stage II; this necessitates a telescoping of the tail, caudal spine, and bristles of the appendages, the gradual evagination of which gives rise to the peculiar appearances seen at this stage, and which have given rise to some misconceptions.

There is a most remarkable agreement between the nauplii of the various species in the general structure of the carapace, labrum, &c., extending to the minutest detail in the case of the appendages, and indicating that the features in question have been inherited from some stage of the common ancestor.

There are, however, points of difference which concern chiefly the carapace (with its horns and caudal spine), labrum, and tail.

Differences are perceptible in most cases in the new-laid ovum of different forms, and the genera, or even the species, can thus be separated even at this early stage.

The larval differences necessitate a classification which agrees very closely with that deduced from the structure of the adults.

Such differences have, however, in most cases been acquired independently of adult structure, since they concern characters peculiar to the larvæ, and lost by the adult. Some indications of the precocious appearance of characters originally belonging to the later stage are seen in *Balanus*; but most of the characters cannot be so explained. The larva and adult have varied simultaneously, but in quite different ways, each having in this group taken its own course of evolution.

The agreement in the development of such forms as *Balanus* and *Lepas*, stage by stage, indicates that the ancestor of the Thoracica underwent a metamorphosis similar to that of the present members of the group. The *Nauplius* and *Cypris* stage have, therefore, not been evolved within the group.

* This term is used in a purely descriptive sense.

The embryonic development, though in its main lines very uniform throughout the group of the Thoracica (Lepadidæ, Verrucidæ, Balanidæ), shows considerable variation in some respects, and the variable features are the same in all the species.

The most conspicuous variations are those which affect the processes of cell division. The details of the mode of growth of the blastoderm over the yolk, from the appearance of the basal plane to the closure of the blastopore, and the resulting cell arrangements vary indefinitely. After the closure of the blastopore, the yolk endoderm cells present in their mode of division an almost equally great diversity.

The size, shape, and colour of the ova and embryos of a species vary not inconsiderably.

In size and shape the nauplii of a species vary somewhat; but no conspicuous variations occur in structure, the larvæ always showing a great amount of uniformity, even in so minute a feature as the character of each bristle belonging to an appendage. Minute variations occur in the ornamentation of the carapace, caudal spine, and tail, and (in *Chthamalus*) in the number of teeth at the end of the labrum.

XV. "Thermal Radiation in Absolute Measure." By J. T. Bottomley, M.A., D.Sc., F.R.S. Received June 16, 1892.

(Abstract.)

The paper contains an account of an experimental investigation by the author in continuation of researches on the same subject which have been already published ('Roy. Soc. Proc.,' 1884, and 'Phil. Trans.,' 1887). In the earlier experiments metallic wires heated by an electric current were used. The loss of heat from a heated body, however, depends to some extent on the form and dimensions of the body, and it seemed important to experiment on the loss of heat from bodies differing in form from the wires already used, and larger in dimensions.

Accordingly, two copper globes used by Mr. D. Macfarlane in 1872 ('Roy. Soc. Proc.,' 1872, p. 93) were employed for a new series of experiments.

After preliminary experiments (using the same enclosure which Macfarlane employed, and with the surfaces of Macfarlane's globes prepared in four different ways) new apparatus was constructed; the object being to experiment both with full air pressure and with different amounts of exhaustion of the air, and Macfarlane's enclosure being unsuitable for this purpose.

In the arrangement adopted, the heated globes were hung at the